5G Rural Integrated Testbed

D4.3 Final Report - Livestock and UAV Use Cases

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Executive Summary

The project forms part of the Department for Digital, Culture, Media and Sport 5G Testbeds & Trials Programme (5GRIT), designed to assess the capabilities provided by 5G infrastructure in rural areas.

This report (Deliverable 4.3 of the project) is designed to deliver an overview of the achievements realised through the combined utilisation of 5G infrastructure, UAV survey and smart data processing in order to support a range of efficiency, cost and wider business benefits related to operation of an upland livestock farm (WP4).

In terms of the background for understanding capabilities of the 5G network, it is considered to provide a step change in the speed and volume of data which can be transmitted from rural areas. This ability provides opportunities to create use cases based on data transmission in rural areas which so far, with 3G and 4G, have not been possible.

The report details outcomes against two specific research questions:

- understanding the ability of a 5G network to enable robust UAV operation and data transmission at range within an agricultural context.
- The utilisation of UAV imagery capture, combined with smart AI based computer-vision analytics to support various agricultural benefits and applications.

The above questions were matured into a single context of conducting UAV remote survey of grazing livestock (primarily sheep), within a remote upland farm environment (selecting a 600Ha farm outside of Slaggyford, Northumberland)

Four core 5GRIT partner organisations directly supported achieving the aims of this use-case; Blue Bear systems research (UAV service provision), Quickline Communications (5G infrastructure), Kingston University (AI based data analytics) and Precision Decisions (Agri-business analysis).

Following significant development, made by each project partner over the course of the project, the report details the culmination of activity, achieved during the period of August/September 2019 with the conduct of final flight trials.

As a key output of the project, the 5G network infrastructure, installed at the farm in Northumberland and Precision Decisions' office in Yorkshire, was demonstrated to enable robust flight operation and communication of applicable in-flight telemetry and video data with minimal degradation such to enable support remote command and control of the UAV from the Blue Bear offices in Bedfordshire (>200 miles away). In-field transmission of captured survey data to remote cloud-servers over the deployed 5G network was repeatedly shown to complete around 3 to 4 times faster when compared with existing 4G data speeds.

From the aerial survey approach conducted, it was possible to achieve full coverage of the 600Ha upland farm site within an 8.5hr period, however with optimisation of flight survey conduct, including flight routeing development (based on required resolution) and optimal

UAV platform and sensor payload it was considered that robust survey could be achieved in much less than half this time.

The development of the AI livestock detection algorithm conducted by Kingston University and utilised to survey and assess livestock (specifically sheep) numbers, achieved 86% accuracy through optimisation of Single-shot detection algorithm and sliding-window techniques. With additional data-set training and optimisation for wider detection targets it is considered that this accuracy value can be further improved, with the potential to support further livestock analysis (capture over pro-longed grazing periods) and wider agricultural applications.

In regard to envisioned cost benefit, business analysis conducted by Precision Decisions, working closely with the farming community during the project, suggested time savings (through remote UAV farm survey) could enable reduced labour requirements of ~£600pm. Furthermore additional cost efficiencies could be enabled (including factors such as early identification of livestock health) and enabling farm security benefits through regular remote aerial surveillance.

Importantly, It is considered that evidence gained through remote UAV operation as part of a 5G capability can be utilised to support CAA legislative development related to BVLOS operation (and the related Blue Bear NBEC facility) as well as demonstrating evidence to support future 5G hardware/infrastructure adoption suited to Small UAS integration.

1. Introduction

As part of the Department for Digital, Culture, Media and Sport (DCMS) 5G Testbeds & Trials Programme, this paper reports on the output results and lessons-learnt under WP4 of the 5GRIT project, specifically, the assessment of the ability of 5G network connectivity to enable Unmanned Aerial Vehicle (UAV) operation and smart data processing in support of rural (upland) livestock farming applications. Written contribution from three of the 5GRIT consortium partners is incorporated below based upon the applicable specialisms of each:

- Blue Bear Systems Research: UAV systems integration and managed service provision
- Precision Decisions: Agronomy and Agri-business consultancy provider
- Kingston University: Smart AI-based data analytics and decision output

2. Research Question- what we set out to achieve

Two specific research areas were to be investigated as part of the 'Agriculture' 5GRIT work strand:

1. Developing understanding of the ability of a 5G network to enable robust UAV operation and data transmission at range within an agricultural context.
2. The utilisation of UAV imagery capture, combined with smart AI based computer-vision analytics to support various agricultural benefits and applications.

In order to demonstrate the capabilities of 5G for smart-farming applications, the project envisaged a data acquisition and relay capability, utilising a UAV (with imaging sensor), monitored and controlled over a deployed 5G network. This would enable multi-spectral imagery capture across farm sites and the transmission of this imagery over the deployed network for artificial intelligence based computer-vision analysis to be conducted.

The following objectives were set:

- Demonstrate a (UAV based) remote monitoring system to assist farmers in enabling survey of large farms with relative ease and speed
- Utilise computer vision algorithms to monitor livestock over large farms for identification, verification and distribution of livestock presence
- Understand the ability to command and control a UAV over the 5G network (supporting future case for BVLOS operation)
- Understand the ability to relay and transmit in-flight and post-flight imagery data in-field over the 5G network

3. Implementation

During the 5GRIT contract period, a wealth of development and testing has been conducted by the 5GRIT partner organisations in advance of the period communicated within this report by which to enable WP4 (Livestock use case) to be fully assessed and demonstrated.

The following details an overview of this prior activity, noting further detail is available within previously published project Interim reports (*D3.13 Agricultural Use Cases – Interim Final Report*).

3.1 5G Infrastructure

Quickline Ltd, a communications provider, have previously conducted installation and set-up of 5G infrastructure at the locations selected to support conduct of the livestock survey use-case. These installation locations include the Blue Bear Head Office and their Twinwoods flight trial site (Bedfordshire), the Precision Decisions office (Yorkshire) and the Alston Livestock flight test site (Slaggyford, Northumberland). The installation incorporates emplacement of 5G Cambium network Medusa receiver/transmitter units, operating at 5735MHz (20MHz channel) and connected to local cable internet connection as applicable. An overview of the 5G network configuration is included in Figure 1 below.

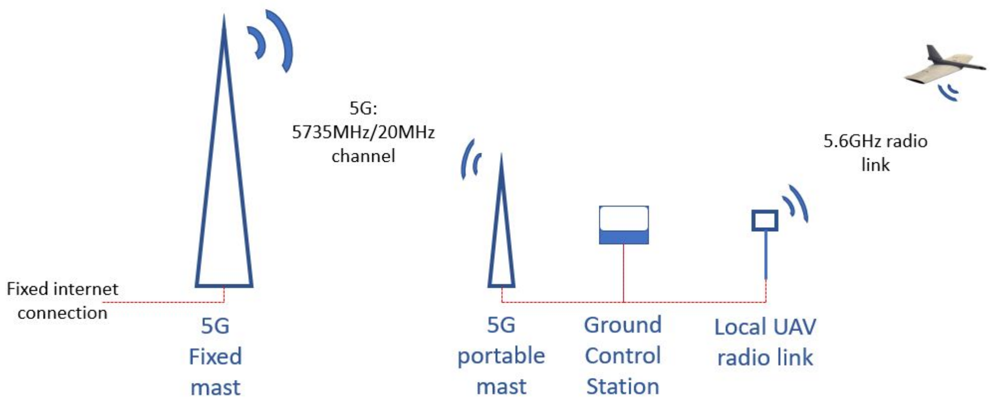

Figure 1: Communications configuration for UAV operation

3.2 UAV Operation and Data Relay

As part of support to the Livestock use-case, Blue Bear have conducted configuration and flight development of the 'Agri-Start' UAV platform, specific to the agricultural use-case. This includes development of 5G local network system design and development. The configuration (discussed later within this report) incorporates local radio-link connectivity with the UAV and the ability to enable network control over the deployed 5G infrastructure.

Extensive flight operation, optimising sensing payload and configuration (RGB and Multi-spectral) has been conducted, this includes configuration of Blue Bear flight control software (specific to the agricultural use-case) and the conduct of in-flight data capture to support development of both the Livestock and arable use-cases (the latter reported separately).

As part of the build-up to the Alston flight trials, Blue Bear (with support from Quickline) were able to successfully demonstrate the first UK 'over 5G' UAV flight conduct at their Twinwoods test site in Bedfordshire. The demonstration confirmed proof of the ability of the 5G network to enable the Blue Bear 'Agri-Start' fixed-wing UAV to be directly monitored and controlled from a remote operator based off-site at Kingston University. File transfer of collected data was also conducted via direct upload over the 5G network to the Kingston cloud-server for analysis. This successful conduct allowed the team to progress to trial/demonstration of the developed capability in direct support of the Livestock use-case at the farm site in Slaggyford, Northumberland (as reported below).

Figure 2: Blue Bear 'Agri-Start' UAV

3.3 Agri-business consultancy

As part of the development and assessment of the Livestock use-case, Precision Decisions have integrated with the project partners to conduct analysis of the UAV survey data and outputs generated through the deep-learning algorithms (developed by Kingston University). Based upon organisational knowledge of the Agricultural domain and through work with the farming community to understand the benefits foreseen through the use of UAV survey/automated data output techniques, Precision Decisions have generated supporting evidence, documented later within this report.

3.4 Data processing and analytics

3.4.1 Background

In the build-up to this final reporting period, Kingston University have explored and developed deep learning techniques to enable livestock detection from UAV images. In particular, the single shot multibox detector (SSD) is applied to achieve automated detection of livestock from the UAV images and then count them. The SSD algorithm is an open-source, object detection algorithm that is widely used by the computer vision community.

A framework for an automated livestock detection based on deep learning technologies was developed and presented previously in the interim report. The initial framework explored advanced deep learning methods such as image super-resolution, generative adversarial networks (GAN) and you only look once (YOLO) object detector for analysing aerial images of livestock captured during the flight trials from Blue Bear Systems Research. The aim of the image analysis was to detect livestock from the images and get a count of the livestock. A detection accuracy of approximately 57% was obtained with the initial framework that was promising, however, higher detection accuracy was desired.

Further investigation identified that in aerial images, the livestock are represented as small objects as the UAVs capture images from a high altitude as shown in Figure 3 below. Deep learning based object detection models often require good resolution of objects in the images to learn the object features and develop the *intelligence* to detect them independently.

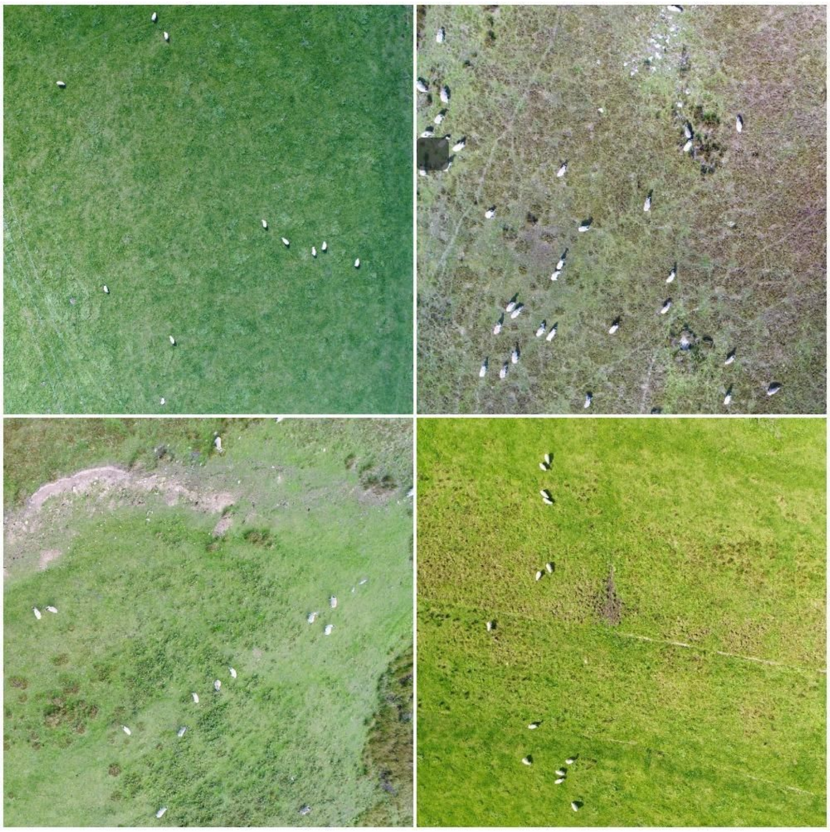

Figure 3. Example images of the livestock dataset. In the images, sheep are small targets for the object detectors

Due to the small sizes of the livestock in the aerial images, the state-of-the-art object detectors were demonstrating relatively lower detection performance. This occurs because small objects in images do not have enough feature representations that a deep learning model can learn from for prediction. An explanation of this phenomenon is given in Figure 4.

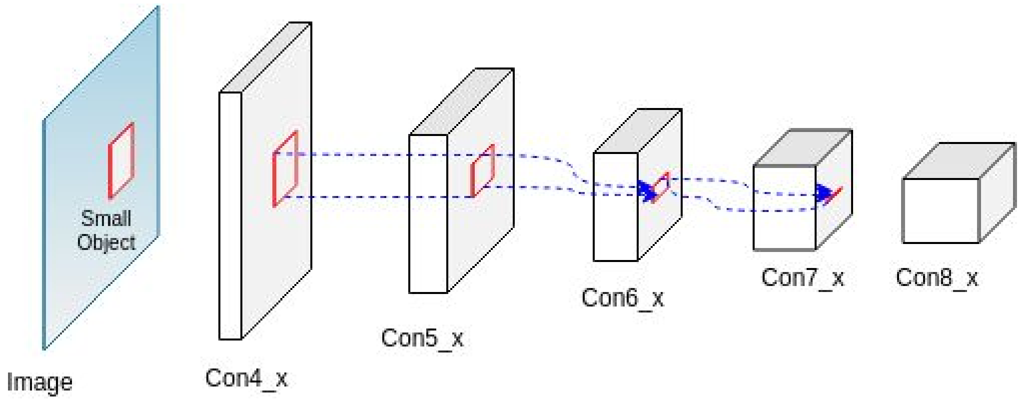

Figure 4. Small object feature representation at deeper layers of a convolutional neural network. The object features are downsampled at each layer. Small objects risk losing feature representation at the prediction layer at the end.

An object detector based on convolutional neural network has multiple convolutional layers. At each layer, the image is down-sampled for feature extraction and learning. All the features extracted are fed to a prediction layer at the end where the detector learns to predict the object. For a small object in an image, the features of the object may disappear before it reaches the prediction layer and hence the detector does not get enough features to learn and predict.

3.4.2 Single Shot Multibox Detector

To address the small object detection problem for livestock detection, a class of object detectors that operate on multi-scale feature layers were explored. A popular state-of-the-art object detection model called Single Shot Multibox Detector (SSD) was adopted for livestock detection. The aerial images acquired were of very high resolution. Due to graphical processing limitations, the high resolution images were split into multiple images of 300x300 resolution. The smaller resolution images consists of sheep images and they were used as a database to train the SSD model for learning and prediction. With this approach, the detection accuracy improved to approximately 72%. Thus, the SSD algorithm helped in improving the detection accuracy from 57% by the initial framework to 72% accuracy. The Figure 5 below shows detection results from the SSD algorithm. The bounding boxes on the sheep are the predicted boxes by the SSD algorithm.

Figure 5. The detection results obtained from the SSD algorithm. The red bounding boxes indicate the detection performed on the split aerial images.

The SSD algorithm provided improved detection accuracy, however, there were a few shortcomings.

- With SSD algorithm alone, it was not possible to detect livestock on the original high resolution image acquired. Additional methods were required to be able to achieve livestock detection on an entire image

- The detection accuracy, though improved to 72%, could still be improved further. Adapting SSD was necessary to suit the requirements of the aerial images and further improve the detection performance.

3.4.3 Extended SSD Algorithm

In the next stage of experiments, the standard SSD algorithm was extended with additional modules to improve its detection performance on the livestock images. For this purpose, two modules, a deconvolution module and shallow feature concatenation module were added to the SSD model.

- The deconvolution module performs an operation through which the downsampled features of the objects are increased in resolution so that they have better representations at the prediction layer. This process helps in improving the detection performance.
- The second module added to the SSD algorithm is the shallow feature concatenation layer. As mentioned earlier, a deep learning model has multiple layers where features are progressively downsampled and at each layer object features are learnt by the model. The object features are well represented in the shallow layers. We take advantage of the feature information available at the shallow layers and concatenate them and present it at the prediction layer to further improve the prediction

performance. An illustration of the modules added to the SSD algorithm is shown in Figure 6.

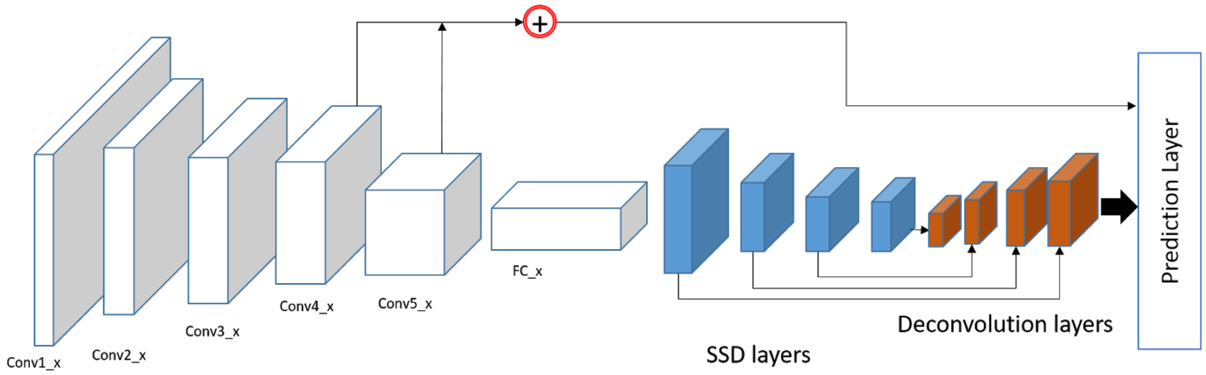

Figure 6. Proposed extension to SSD model with a deconvolutional module and feature con-catenation module to improve small object detection accuracy.

Our extended SSD algorithm was then trained on the livestock dataset. Finally, to enable detection on the entire high resolution image, we used a “sliding window” approach in which the SSD algorithm is applied on the image in chunks across the entire high resolution image. This process mirrors a sliding window and hence referred to as sliding window approach. The advantage of this approach is that it enables faster processing of the image by the SSD algorithm and the detection on the entire image is done patch by patch resulting in improved detection performance.

The additional modules implemented on the SSD algorithm and the sliding window approach is a novel framework developed under the 5GRIT project for the livestock detection use case. This object detection framework helped in gaining a high detection accuracy of approximately 86% on the livestock images. The images in Figure 7 illustrates the detection performance by the extended SSD algorithm. The novel framework is an important research contribution as it addresses the small object detection problem in aerial images.

Figure 7. Livestock detection results obtained by the extended SSD algorithm. The red bounding boxes on the sheep illustrates the detection performed by the algorithm.

4 Key Learning Points

4.1 How the use of UAVs within a 5G network reduces time required to monitor & survey livestock

As a culmination of the network integration and trial flights completed previously in the project, the following information within this section details the flight conduct, carried out by Blue Bear Systems Research during the period of the 17th – 20th September at the farm site in Slaggyford, Northumberland, as a sample use-case for remote survey of upland livestock.

4.1.1 Data capture

Figure 8 below details a sample of RGB flight survey completed during the use-case assessment period.

Figure 8: Sample of RGB flight survey

Table 1: Flight survey locations and associated flight data

Location	Flight duration (mins)	Power draw (%)	Capture Area (Ha)	Flight: Pre-set AGL (m)
1	9.00	30	16.79	80
2	7.00	22	8.20	80
3	8.00	10	7.76	80
4	21.00	58 (1), 25 (2)	13.87	40
5	15.00	42	13.20	60

6	18.00	62	21.66	60
Total	**78.00**	-	**81.48**	-

During the use-case assessment, a total capture area of 81.48ha was completed within a (total) flight time of 1hr 18minutes (totalling 1661 images captured).

At an operating altitude of 80m, and an overlap of 70%, it is reasonable to expect that aerial survey of 607 hectare farm site (as per the Slaggyford farm trial site) could be achieved in a period of ~8.5 hrs, notwithstanding (current) battery changes and supervisor relocation (to remain within CAA operating limits). It is however important to note (as per Table 1) that a number of flight capture parameters can be seen to have significant impact upon the total flight duration (and associated UAV power consumption). These parameters are discussed in detail in later sections of this report.

4.1.2 (Captured) Data transfer

As part of the Alston use-case assessment, data transfer, of collected RGB imagery data (using a 1GB sample packet) was conducted at three separate ground locations (of varying elevation) across the Slaggyford farm site. The conduct of the data transfer involved the set-up of the Cambium network receiver unit (positioned on a portable 5m mast) at each location (depicted in Figure 9 below), with upload of the data-file to the Kingston cloud-server.

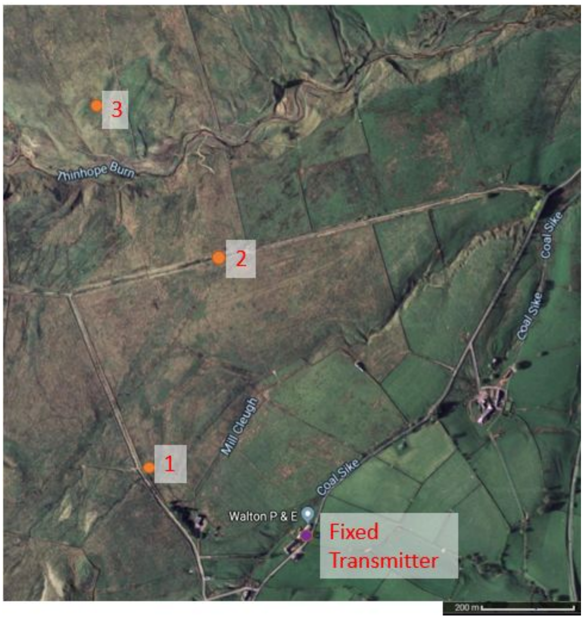

Figure 9: Overview of 5G receiver mast deployment

Table 2 below communicates the outcomes of the transfer assessment.

Table 2: Recorded file transfer speed by receiver mast position

Ground mast location	Distance from Transmitter (m)	File size (MB)	Upload time taken (s)	Assessed Mbps (upload speed)
1	337	1000 - ~5ha (~500 Multi-spectral images)	230	34.78
2	601		220	36.36
3	990		218	36.70

The results suggest a consistent upload speed was achieved at each location, with range not assessed to be a key factor to the 1km explored. The upload speeds achieved (around 35Mbps) compare favourably (3.5 times faster) against a 'typical 4G LTE upload speed of 10Mbps*[1].

It should be noted that for each location, the deployed receiver mast was considered to be within/close-to line-of-sight with the building-mounted transmitter. Based upon prior evidence captured within the project (and reported previously), it is reasonable to suggest a drop-out in connection speed would occur where line-of-sight could not be achieved. Detailed link assessment results per mast location is included within Table 3 below.

Table 3: Detailed link status per in-field position

Blue Bear Cambium Network 5G link speed assessment:			
Ground mast location	1	2	3
Position	54° 52' 23, -2° 31' 33	54°52'372°31'26.1876	54°52' 46.4154,-2°31' 41.2392
Distance to transmitter (m)	337	601	990
Elevation (m)	290	280	280
Downlink (Mbps)	102.10	69.96	102.25
Uplink (Mbps)	44.05	42.88	43.91
Packet Transmit - actual (Mbps)	41.80	40.98	41.85
Packet Receive - actual (Mbps)	97.00	66.40	97.00
Receive Power (dBm)	-40.9	-53.5	-52

4.1.3 Data utilisation benefits

The custom livestock detection analytics provides capabilities to automatically detect the livestock and provide a count from the captured farm images. The analytics are helpful for the farmers as it provides them an overview of the distribution of their livestock across the farm. On the display screen, the farmer can view where the livestock are located on their farms and obtain a count. This automated approach reduces farmer`s efforts and time to

[1] www.4g.co.uk/how-fast-is-4g

manually survey their farms on a daily basis which is often time-demanding and high effort activity.

Figure 10: Sample RGB survey output image file

4.1.4 5G enabled Remote UAV operation

As part of the Alston livestock survey use case, remote operation of the Blue Bear Agri-start UAV was demonstrated, utilising the deployed 5G network.

Within the demonstrated use-case, command and control of the Agri-start UAV was conducted from Blue Bear's head-office in Bedfordshire through remote 5G access to the on-site Ground Control Station (represented in Figure 11 below).

Figure 11: Remote Ground Control Station operation (left) enabling remote command of Blue Bear fixed-wing UAV (right)

In order to assess the capability and robustness of the 5G link, comparative performance assessment was conducted to baseline the local network video data transfer rate (frame transfer and loss) and compare these local recorded values with those received over the 5G network by the remote operator (at the Bedfordshire site) as a measure of 5G network performance. The in-field Blue Bear network configuration is demonstrated in Figure 12 below.

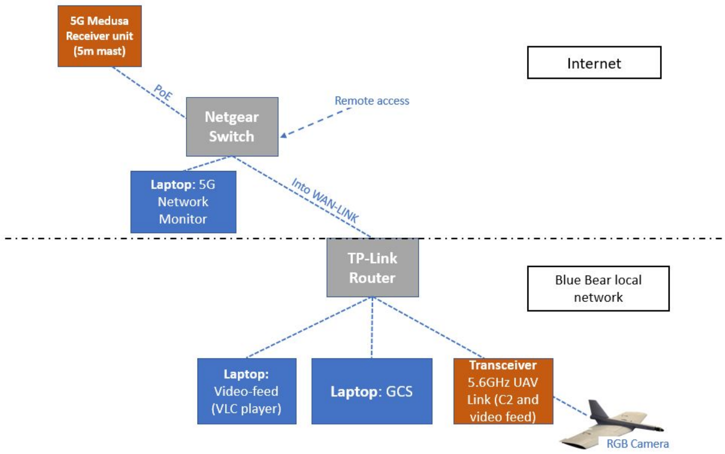

Figure 12: Blue Bear in-field configuration

The table below details the results of the 5G in-flight data transfer assessment. To account for any impact of in-field mast location (in relation to the fixed transmitter mounted on the farm buildings), two in-field portable mast locations were explored (as per Figure 9), with live video-feed data from the on-board camera communicated back to the Bedfordshire HQ via remote network access. The key measure for indicative assessment is 'Frames Lost'.

Table 4: Comparison of 5G mast location on remote flight conduct

GCS (mast) position	1		2	
Video-feed recipient	On-site	Remote (5G)	On-site	Remote (5G)
No. of Frames (displayed)	10000	9729	9946	9922
Content bitrate (kb/s)	300	3398	363	3340
Frames Lost	8	15	59	130
Frames Dropped	2	2	2	2

As can be seen within Table 4, for each of the two mast locations trialled, the number of 'lost frames' was around twice as many for the (over 5G) transmission than that experienced locally (accepting subtle differences in the number of frames displayed). This suggests live-feed flight data, when communicated through the employed network configuration, experiences a degree of degradation.

Importantly, the network capability, was sufficient to continue to enable robust relay of in-flight video and telemetry data such that, in the use-case demonstrated, the remote operator was able to continue to enact command and control of the UAV based on the quality/latency of the data provided over the 5G network link. Figure 13 below demonstrates a 'still image' taken from the on-board video received at Bedfordshire site.

Figure 13: Still image from UAV live video-link, received at Blue Bear (Bedfordshire) site over 5G network

4.2 How does the use of UAVs within a 5G network assist the farmer to improve the health monitoring of livestock?

The live-stock use-case focused on the counting of sheep, which hill-land sheep farmers undertake on a daily basis, taking up a lot of their time. Large and extensive farms can be hard to manage with vast amounts of land to be covered to track animal movement. This means animals can be hard to locate, and it can be difficult to spot abnormalities in animals' behaviours.

Often, especially in the summer months, hill sheep graze on fell pastures which can be a number of miles from the farmhouse. These fells are also quite extensive and the sheep have a large area to roam. Farmers need to know on a daily basis where their animals are and whether they need help if sick or injured. To do this, farmers go out daily to monitor their animals. These are counted and observed and this entire operation can take up to three hours per day depending on the number of animals and the distance of the fell from the farmhouse.

The use case was derived to assess if the use of a UAV, streaming live images back to an office where, following appropriate image processing, an algorithm will estimate the number of sheep on the fell and give an indication to the farmer of any potential sick or injured animals. These often separate themselves from the main group of animals so can be detected.

Feedback from the farmer has suggested that there are three main benefits to the remote observation of his animals using UAVs:

- He can save time each day knowing where the sheep physically are;
- He can observe remotely the possibility of an animal being in distress or sick by observing a different behavioural pattern that the flock;

- He can potentially treat animals individually since these are now identified, rather than treating the whole flock. This could reduce animal health and medication expenses.

In addition, the farmer mentioned that a key element of his work was to ensure the overall welfare of his animals. Regular flights and data acquisition of the livestock can be helpful for monitoring the overall wellbeing of their livestock. For instance, images taken over multiple intervals of time can be analysed by the farmer to gain insights into the grazing patterns and the movement patterns of their livestock across the farm. This information helps in improving their understanding of the livestock status and contributes towards their decision making for various farm activities. Further, in the future versions, the livestock detection system can be extended to identify anomalies such as slow-moving livestock or stagnant animal (sick or dead) from multiple flights over the farm region. This helps in quick identification of disease or other possible welfare issues in the herd.

4.3 How does the use of UAVs within a 5G network assist the farmer to Increase the productivity/earning potential of the farmer and thereby the viability of remote farms

The economic use case for this concerns the closer monitoring of the farm animals – in this case sheep – which enables cost benefits to farmers in two ways:

1. An overall reduction in medicine usage due to a targeted approach to animal health rather than a prophylactic approach. Current median spend is £6.82 per animal, per year on a hill sheep farm. We estimate that a 5% reduction can be achieved through this targeted approach which results in a cost saving of £0.34 pence per animal on veterinary products. On a farm with 895 sheep (average size), this would equate to £0.34x895=£304 per year.

2. We think that, as a result of better monitoring of animals grazing in remote areas, monitoring for disease and health issues (such as inflamed hooves) can be improved and the issue identified earlier. In discussions with farmers, we estimate that 1 call per year could be saved as a result of monitoring the animals more closely. This equates to a saving of £50-£90 p.a. based on the current cost of a vet call out on these farms.

Overall, both savings could amount to £350 - £390 per year on the average sheep farm. While this is rather low, with today's very small margins of such farms, this is a sizeable contribution.

The main contribution to the economics of the hill farm would be the time saving as a result of the UAV service providing data about where the animals were located. The time saving is estimated at 2-3 hours for each time the farmer would normally go out to observe his sheep. This time can be spent doing other non-farm related work.

The value for this is difficult to estimate but if we take an hourly rate of £10 per hour, the additional income could be up to £30 per day, £150 per week or £600 per month, which placed alongside the low margins achievable in hill-land sheep farming, is considerable.

4.4 Does the availability of a 5G network enable the farmer to improve the security of his livestock and equipment?

There are a number of opportunities where the technology can be used to improve safety and security:

- Operator safety: Farmers use quad bikes or similar to monitor their animals in far and remote locations. They can often be away all day and be out of contact with their home office. In the event of an accident, for example if the quad bike overturns, the operator would only be missed late in the day as no-one would expect them back before then. This could be too late. A network in remote areas would enable the operator to call for assistance in the event of an accident. Some machines have so-called "topple alarms", which automatically send a text message to a pre-determined contact such that help can be sent. This is especially useful if the operator is incapacitated and cannot use the mobile phone.

- Machinery theft: this is an increasing issue in remote rural areas. Quad bikes and other smaller machines are easily removed from premises by thieves and can be a very long way away by the time the theft is noticed. A good rural network would enable machines to be fitted with small, relatively low-cost trackers which could track and locate the machines in the case of theft. Just the presence of the trackers can act as a deterrent to thieves. Insurance companies are interested in this technology and some premiums can be reduced as a result of applying trackers to machines.

- Animal theft: this is also an increasing problem with sheep and cattle being removed from fields under cover of darkness. A mobile broadband network would enable automated security measures to be put in place, such as cameras and even UAV carried cameras which can observe the thefts, which significantly increases the chance of catching the thieves. Again, often the risk of being filmed will act as a deterrent.

The physical security collaboration project is discussed in further detail in Appendix A.

5. **Wider project outputs**

5.1 Ground infrastructure

The physical emplacement of both the 5G transmitter and the fixed/portable Cambium receiver unit was considered to be significant in impacting network data speeds and reliability when 'in-field'. Transmission ranges (between fixed transmitter and mobile mast-mounted receiver) of <3km were explored as part of the flight-conduct. Whilst range alone was not considered to noticeably degrade achievable data rates, the specification of receiver antenna utilised was sensitive to angular changes, with degradation occurring once the limits of the forward-arc were reached (typically >10 degrees from centre).

Obscuration of the signal, both as a result of dense vegetation and wider ground relief factors constraining the ability to achieve direct 'line of sight' were also noted to impede the resultant connectivity. This 'line-of-sight' requirement was noted during installation of associated hardware at the Blue Bear Twin-woods test site, and during operation at the Northumberland farm trial site.


5.2 Additional aerial data utilisation

Under the scope of the project, the focus for utilisation of the collected data was targeted at supporting the livestock assessment use-case, it is however considered that, should regular aerial survey flights be conducted, the captured data can have wider utility beyond simply informing livestock tracking.

Figure 14 below demonstrates the achievable outputs when the 2D RGB imagery collected from the survey flights is post-processed into a stitched 3D mosaic. With software products already available within the domestic/non-commercial market, it is feasible to believe that a 3D virtual environment such as that demonstrated could be readily created to support wider agricultural land-management applications.

Figure 14: Sample 3D mosaic based upon 2D captured data

It is considered that the utilisation of such a 3D (or indeed 2D) software model could support not only agronomic assessments but also in enabling factors such as seasonal hedge-line growth, boundary fence/wall integrity and local environmental changes to be monitored and assessed through virtual manipulation of the data models.

6. **Future Work**

6.1 Detection algorithm development

During the course of the 5GRIT project, the livestock detection analytics development has progressed significantly with the detection accuracy progressively increasing from the initial 57% to up to 86% in the final framework. There is still room for improvement for the detection performance and future work will consider on further extending our developed framework to reach detection accuracies above 95%. Some of the planned activities in the future work are:

- Livestock data captured at different altitudes to be used as training dataset for the object detection algorithms and analyse the impact of altitudes on the detection performance. At different altitudes, the livestock data are captured at different resolutions that can influence the detection performance. Therefore, it would be insightful to investigate the altitude impact on livestock detection.
- Source larger volumes of livestock data to improve the training dataset volume and thereby increase the detection accuracy. Deep learning models require large volumes of data that covers different variations of the target data in order to achieve high detection accuracy. Therefore, attempts will be made to acquire more varied data to further improve the livestock detection accuracy.
- Adapt the custom object detection algorithm developed for livestock use case into a general object detection algorithm for analysis of aerial and satellite images. The algorithm addresses small object detection problem common in aerial images. The algorithm can be adapted and applied for various applications such as satellite image analysis, crowd monitoring applications, surveillance systems, vegetation monitoring and other similar areas.

6.2 Regulatory factors

As has been communicated within previous project reporting, the UK regulatory environment currently inhibits two operational factors related to full adoption of 5G remote UAV operation being fully assessed and demonstrated under this phase of the project. These two factors are;

- The BVLOS operation of a UAV, and the local safety pilot requirements
- The direct connectivity of a UAV through a 5G Mobile Network

6.2.1 CAA Regulation

Current operation of the class of UAV's utilised during this phase of the 5GRIT project constrains operation to within Visual Line of Sight (VLOS) conditions, that is <500m horizontal distance, and <400ft altitude.

Whilst Blue Bear were able to demonstrate 'over 5G' command and control of the 'Agri-Start' UAV from off-site Ground Control Station locations across the country, a local 'safety pilot' was required to be (on-site) within VLOS conditions of the UAV at all times, able to re-take local manual control should it be required for safety purposes during operation. This meant conducting multiple individual survey flights (to maintain safety pilot line-of-sight) and then physically relocating as opposed to maximising efficiency and conducting a single flight capture across the entire farm site.

The above procedural requirement is currently considered impractical in achieving the envisioned use-case of truly remote survey with little to no direct human interaction required.

It is considered that the flight data and wider use-case understanding achieved throughout the duration of the project can be used to support evidence pertaining to utilisation of selected frequency bands of the 5G network, enabling robust transmission of in-air flight data at longer ranges. In the immediate term, the collated data will be used to further inform operation of the National Beyond visual line of sight Experimentation Corridor (NBEC), a collaborative facility operating between Cranfield University and Blue Bear's Oakley facilities, within which the CAA Innovation team are closely integrated.

6.2.2 OFCOM licensing

As has been previously reported, a 5G communications link, directly between the aircraft and the associated local flight control software was not demonstrated under this phase of the project. Instead, the deployed 5G network was utilised to communicate flight telemetry and control from the primary GCS to a secondary GCS located off-site.

A number of key factors prevented direct in-air operation of the 5G network during this phase of the project;

- The current size/weight envelope of the 5G transceiver units made available under the project are not currently suited to mounting within a sub 20kg class CAA compliant UAV platform.
- The Cambium network 5G equipment provided as part of the project is designed to enable ground-based point to point communications, as opposed to omni-directional functionality required as part of a moving (in-flight) communications link.
- Regulatory factors and contract partner intent communicated at project start-up did not endorse flight of 5G equipment.

As development of 5G enabled communications equipment continues, and regulatory aspects enable development/temporary use-license endorsement suited to air-frame integration, it is considered that the restrictions experienced upon project commencement will become sub-seeded.

6.3 Flight operation

Throughout Blue Bear's conduct of aerial survey in support of both the agricultural use-cases, a number of factors have become apparent related to future optimisation of flight conduct by which to benefit cost-effective operation.

The current Blue Bear operated data capture software enables a target capture area to be achieved through automated flight path generation based upon a number of operator defined input parameters

There are a number of flight capture parameters that can be seen to have significant impact upon the total flight duration (and associated UAV power consumption). These factors considered to have the most impact are flight altitude (AGL) and % overlap (between flight tracks) of image capture.

As standard, an overlap percentage of 70% (both horizontal and vertical) was utilised for RGB Imagery capture, based upon optimisation in line with the contract partners and to enable robustness in adverse/unpredictable environmental conditions

Table 5 and 6 below demonstrate the impact of both flight altitude and % overlap on the proposed flight duration.

Table 5: Representation of flight requirements based upon RGB survey of 16.8Ha field at 70% overlap

Altitude (AGL)	Proposed flight duration	GSD (cm/pix)	No. of tracks
40	23 min 3 sec	1.1	18
60	12 min 11 sec	1.64	12
80	9 min 34 sec	2.19	9
100	7 min 30 sec	2.74	7.5
120	6 min 59 sec	3.29	5.5

Table 6: Representation of flight requirements based upon RGB survey of 16.8Ha field at 60m altitude

Overlap %	Proposed flight duration	GSD (cm/pix)	No. of tracks
50	7 min 39 sec	1.64	6.5
60	9 min 24 sec		9
70	12 min 11 sec		12
80	23 min 13 sec		17

Both 'altitude' and 'overlap' directly impact upon the rate at which an area of ground is surveyed. Altitude balances field-of-view (capture area) against achievable resolution, whilst overlap balances capture efficiency against completeness.

As can be seen from the above, a 20m increase in altitude can result in a 20-50% decrease in flight time (field dependent). A 10% overlap reduction results in similar flight time benefits.

As a result, it is feasible to believe that the total capture time of 78 minutes for the 81.5 Ha surveyed at the Slaggyford farm site could be significantly reduced (to a capture time in the region of 40-50 mins) depending on the resolution requirements of any developed AI based post-processing techniques employed and equally, the capabilities of the employed RGB sensor to affect output resolution. Importantly, should an application require only very sparse imagery outputs (for example once a robust high-resolution field model had already been generated or where larger livestock – such as cattle are to be surveyed), the need to enable 'overlap' could be reduced much further as could the data capture rate (based on number of frames captured per area flown) both dramatically reducing required flight capture time (and resultant data size).

6.3.1 Power requirements

Current operating procedure for the multi-rotor platform employed for data collection dictated battery replacement at no greater than 70% consumption per flight. Typically (environmental condition dependant) this resulted in around 20-25 minutes of operation per battery-set.

Whilst the survey software employed enabled the flight capture task to be resumed, short-periods of down-time were experienced whilst the UAV returned to 'base' and a manual operator required to conduct battery replacement.

It is considered that the adoption of alternative UAV platform types (e.g. fixed-wind/hybrid VTOL), combined with the optimisation of flight routeing (overlap, altitude) and sensor payload could enable for a much greater operating duration, and as such, the ability to cover much larger operating areas (in-line with a typical upland farm size) in a single flight operation.

6.3.2 Ground topography

Currently the software employed for wide-area UAV survey operation conducts sensor capture at a single fixed altitude above ground level. This value is determined in advance of flight conduct based on achieving:

- Optimal capture altitude to support required GSD value (typically ~60-80m AGL during trial operation)
- A safe operating altitude, in compliance with regulatory requirements and ensuring elevation suitable to ensure local ground-based obstacles and terrain is avoided.

Whilst the above is practical when operating over areas of limited topographical variation, or ground based obstacles, as can be seen in figure 15 below, significant ground variation in ground profile were experienced during operation at the farm in Slaggyford.

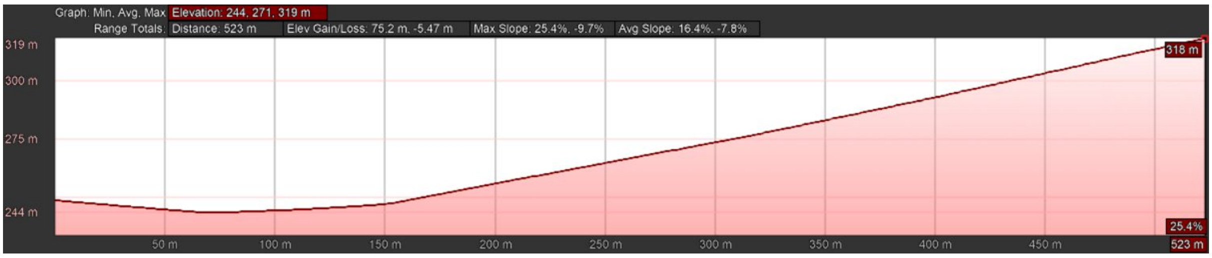

Figure 15: Change in ground elevation across length of capture area '6', Slaggyford Farm

In order to account for the significant elevation variation (around 50m across the section of the field surveyed) the operator was required to increase capture altitude to ensure a safe AGL distance was maintained between UAV and hill-side throughout operation.

As a result of the above a variation in GSD >1.5cm/pixel between the highest and lowest sections of the field was noted, directly impacting on the resultant use and suitability of the data.

It is considered that an ability to achieve a 'terrain following' capability, either through flight profile generation based upon existing digital terrain elevation data, or, to enable the UAV local closed-loop control (based upon on-board sensing) to follow a set AGL value, would result in more efficient, and optimised means of achieving (upland) ground survey, in particular, maintaining a set GSD value across varied terrain.

7 Conclusion

This report details the outcomes achieved and wider lessons learnt as a result of the implementation of a local 5G network, and conduct of remote UAV survey and AI based data assessment in support of the effective operation of an upland livestock farm.

The 5G network infrastructure, installed at the farm site in Slaggyford, Northumberland, was demonstrated to enable robust flight operation and communication of applicable in-flight telemetry and video data with minimal degradation such to enable support remote Command and Control of the UAV from the Blue Bear offices in Bedfordshire (>200 miles away).

From the current flight survey approach, it was possible to achieve full coverage of the 600 Ha farm site within an 8.5 hour period, however with optimisation of flight survey conduct, including flight routeing development and optimal UAV platform and sensor payload (based on use-case specific requirements such as 'quick low data fly-over' as opposed to 'robust high-resolution assessment') it was considered that robust flight conduct could be achieved in significantly less than half this time. In-field transmission of captured survey data to remote cloud-servers over the deployed 5G network was repeatedly shown to complete around 3 to 4 times faster when compared with existing 4G data speeds.

The development of the AI livestock detection algorithm, utilised to survey and assess livestock (specifically sheep) numbers, achieved 86% accuracy through optimisation of

Single-shot detection algorithm and sliding-window techniques. With additional data-set training and optimisation for wider detection targets it is considered that this accuracy value can be further improved, with the potential to support further livestock analysis (capture over pro-longed grazing periods) and wider agricultural applications.

Business analysis of the conducted trials suggested time savings as a result of reduced labour requirements could total ~£600pm, as well as enabling additional cost efficiencies (including factors such as early identification of livestock health) and enabling farm security benefits through regular remote aerial surveillance.

It is considered that evidence gained through remote UAV operation as part of a 5G capability can be utilised to support CAA legislative development related to BVLOS operation (and the related Blue Bear NBEC facility) as well as demonstrating evidence to support future 5G hardware/infrastructure adoption suited to Small UAS integration.